Physical Oxide Properties as a Hardness Assurance Screen for Bipolar Devices

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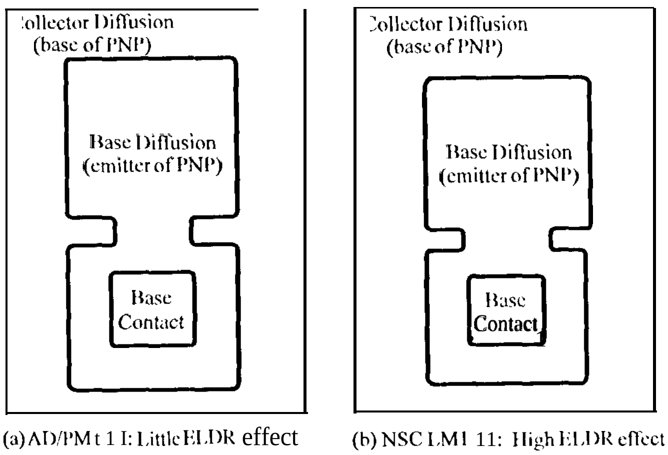
1. INTRODUCTION

The dependence of total dose damage on dose rate for some types of bipolar transistors has been widely studied in recent years [1-6]. Although many device types exhibit this phenomenon, there is still uncertainty about the underlying mechanism and it is generally necessary to do radiation testing in order to identify which devices are susceptible to enhanced low dose rate (ELDR) damage. Devices from some manufactures have no significant ELDR damage, even though the circuit design and device topology is nearly identical to that of other processes with extreme ELDR effects. For example, Figure 1 compares the geometry of substrate pnp input transistors from two different manufacturers with markedly different ELDR sensitivity. Although the circuit topology is nearly the same, there are differences in the thickness and profile of oxides over the pnp emitter-base region.

This paper examines the oxide properties of several different device types, including three different devices produced by one major manufacturer. The physical structure was determined by cutting in a direction normal to the surface, polishing the exposed region, and then using a scanning-electron microscope to examine the oxide and underlying silicon. This process takes only a few hour-s. I'here are clear differences in the oxide thickness and structure of different devices that can potentially be used to distinguish between processes with high and low ELDR effects.



(a) AD/PMI11: Little ELDR effect (b) NSC LM111: High ELDR effect

Figure I. Comparison of Substrate PNP input transistor from two different manufacutrers. (Scaled top view)

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II. EXPERIMENTAL RESULTS

Total Dose Tests at Low and High Dose Rate

Three device types from Analog Devices Inc. (ADI) were irradiated with cobalt-60 gamma rays at high and low dose rate. A dose rate of 50 rad(Si)/s was used for high dose rate testing and 0.002-0,005 rad(Si)/s was used for low dose rate testing.

(a) AD652 Voltage-to-Frequency Converter

The AD652 is a synchronous voltage-to-frequency (V/F) converter with typical linearity of 0.002 % precision. This device has an internal 5 V reference which a designer can use for high precision applications. Usually it is used to offset the non inverting comparator input in the voltage-to-frequency mode.

This V/t' converter is fabricated with a complementary bipolar process using lateral and substrate pnp transistors. This device exhibited large differences in parametric degradation at low and high dose rates, similar to that of other linear devices produced by different manufacturers, but not by most parts from ADI, which have shown little or no ELDR effects. Two parameters were affected: the internal reference voltage, as

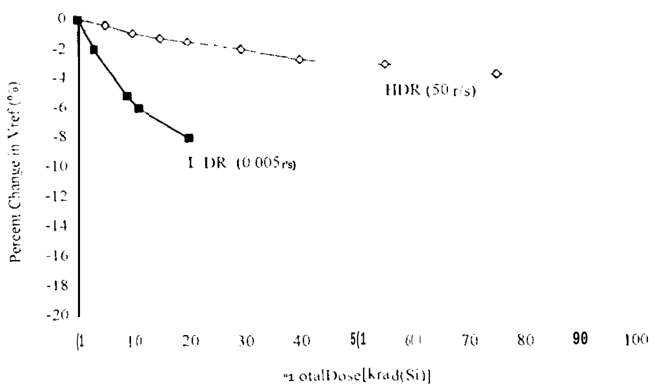


Figure 2. AD652 V/F converter internal reference voltage degradation.

shown in Figure 2, and the voltage-to-frequency linearity which showed much more degradation at a mid-scale voltage. Note that extremely large voltage changes occurred (this part is supposed to have 0.002 % precision), even at high dose rate. At low dose rate changes in reference voltage arc more than s times greater.

(b) ADI PM 1 1 1/NSC LM1 1 1 Voltage Comparators

The second device type, the ADI PM 1 1 1 is a voltage comparator and exhibits little or no enhanced damage effect. The input bias current showed insignificant degradation as shown in Figure 3. However, devices from National Semiconductor Corp. LM 111 with nearly identical geometry (see Figure 1) showed severe degradation at LDR. The cross sections of input pnp transistors for these devices are compared in the later section.

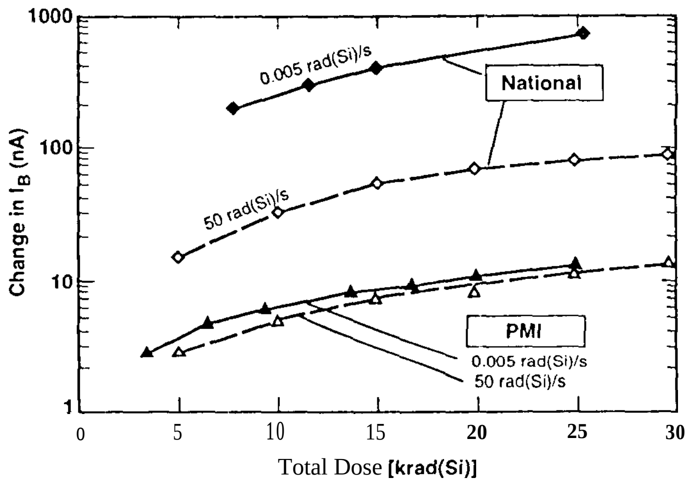


Figure 3. LM1 1 1 input bias current degradation.

(c) AD847 High Speed Op-Amp

The third device, AD847, is a high speed, low power monolithic op-amp. It is fabricated with a junction- isolated complementary bipolar (CB) process. However, the oxide thickness of this device was about twice that reported for the RB25 process [7], and the AD847 exhibited very different behavior for high dose rate and low dose rate. Far more damage occurred at high dose rate than at low dose rate. As shown in Figure 4, extreme degradation occurred in input offset voltage at very low total dose levels, indicating that the oxides in this device are quite sensitive to interface charge trap buildup. Unlike most linear bipolar devices, the damage annealed rapidly after irradiation, even at room temperature. At low dose rate very small changes occurred in input offset voltage, even at very high total dose levels, This behavior is quite unusual in bipolar linear devices, and has not been observed in any of the recent studies of such devices.

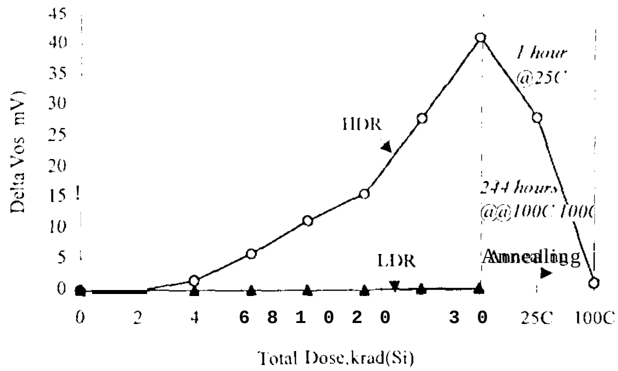


Figure 4. AD847 op-amp input offset voltage degradation. [8]

Oxide Properties

These device types provide an interesting mix of technologies with which to investigate oxide physical properties because of the different way they respond at low dose rates. Samples from each part were cut and lapped, and the cross section of their respective oxides were examined with a SEM.

Figures 5(a) and 5(b) show the oxide structure of the two LM 1 1 1 substrate transistors with different ELDR behavior (see Figure 3). The thin oxide over base region is more than three times as thick for the National device. In addition, the transition contour is quite shallow. These same features appear in Figure 5(c) for the AD652, which also exhibited a high ELDR effect, even though it was from a process produced by a different manufacturer.

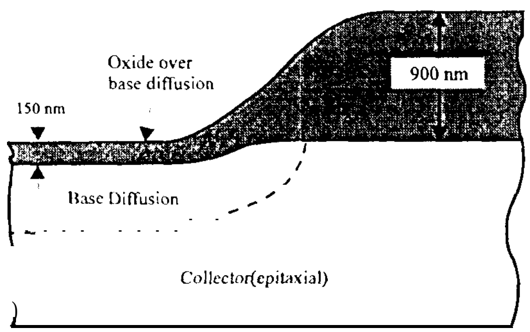


Figure 5(a) ADI PM 1 1 1 with a gradual transition region
(Low ELDR effect)

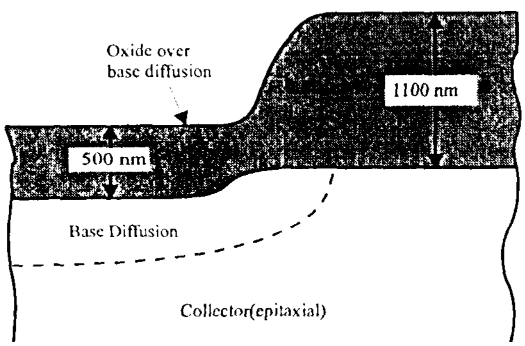
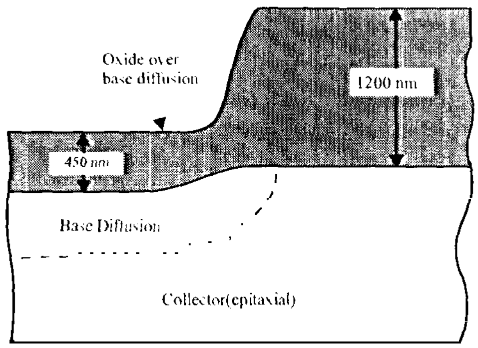
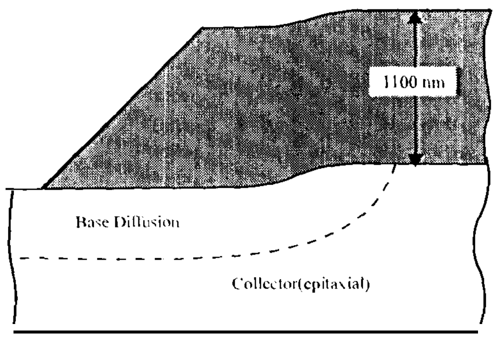


Figure 5(b) NSC LM 1 1 1 with a sharp transition region
(High ELDR effect)



(c) AD652 V/F Converter with a sharp transition.
(*High ELDR effect*)

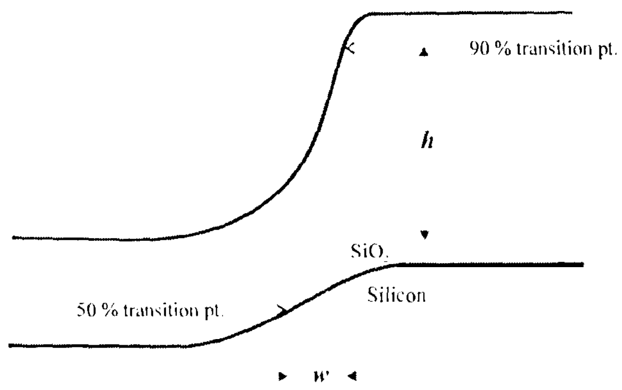


(d) AD847 op-amp with a very small transition.
(*No ELDR effect*)

Figure 5. Four different regions between the base diffusion and thick isolation oxide.

The oxide structure of the AD847 is quite different, as shown in Figure 5(d). This is a different process, with thick oxide over both the base diffusion (pap emitter) and collector region. It behaves more like a CMOS process, with relatively rapid annealing at room temperature. Note that the RB25 process, another complementary process from the same manufacturer, was very sensitive to dose rate effects [7], in contrast to the "reverse" behavior of the AD847.

Based on these malts, two features appear to be important in determining sensitivity todose-mte effects in these types of pnp structures: (1) the thickness of the thinner oxide that is



Transition Ratio = $\frac{h}{w}$

Figure 6. Definition of transition ratio of the oxide structure

thermally grown over the base (pnp emitter) at the end of the base diffusion process; and (2), the contour of the transition between the thick isolation oxide and the oxide over the base region. The oxide structure of a number of devices has been examined in this way. The results are summarized in Table 1. The transition ratio is defined as the height of the midpoint of the base oxide to the 90 % height of the isolation oxide as shown in Figure 6. The other device types with large ELDR effect, appear to have similar properties, even though they are produced with different processes. Note, that devices from three different manufacturers are included in the table. It can be clearly seen that devices with a small transition ratio much less than 1 did not exhibit any ELDR effect. However, devices with transition ratios greater than I observed ELDR effect. The ADIOP42 which uses JFET inputs and a different process has the sharp transition between oxide layers showed an extreme LDR sensitivity and the transition ratio was the largest value.

III. DISCUSSION

This paper shows that there are important differences in oxide structure that appear to correlate with the sensitivity of these devices to dose-rate effects. The shallow transition probably occurs because of a different etching technology. The

Table 1. Oxide Features and ELDR Sensitivity of Several Linear Bipolar Devices

Device	Function	Manufacturer	Isolation Oxide (am)	Base Diffusion Oxide (rim)	'transition Ratio	ELDR Effects
AD847	Op-amp	ADI	Ii00	I100	0.4	Reverse[1]
LM111	Comparator	PMI/ADI	900"	150	0.5	Negligible
LM111	Comparator	NSC	1I00	500	1.2	Very high
LM111	Comparator	Motorola	i150	300"	1.5	Very high
AD652	V/F converter	ADI	1200	450	2 0	Very high
01'-42	Op-amp[2]	PMI/ADI	1250	250	2.3	Very high

1. The AD847 exhibits far more damage at high dose rate than low dose rate
2. The OP-42 uses JFET inputs, and has a more complex process than the other devices in the table.